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Russian forests: A new approach to the assessment of carbon stocks and sequestration capacity

Andrey Filipchuk, Boris Moiseev, Nataliya Malysheva*, Valentin Strakhov

All-Russian Research Institute of Silviculture and Mechanization of Forestry (FBU ARRISMF), Federal Forestry Agency, Ministry of Natural Resources, Russia

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ABSTRACT

The controversy over how to improve the carbon balance assessment for the Russian national forests is discussed. According to the preliminary calculations, three factors are responsible for the underestimation of the carbon sink in Russian forests, up to ≈ 340 ± 75 million tons per year in total: 1. The methodology of assessments. 2. The methodological ambiguity of forest classification, which excludes some areas from managed forests and therefore from assessment, for instance, ≈ 200 million ha of "inaccessible" forests in remote regions and 74.9 million ha of shrubs. 3. The evaluation of the carbon balance for the latest national inventory report under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol (National inventory report of the Russian Federation on greenhouse gas emissions and removals, 2006), which doubled the carbon losses caused by timber harvest and wood removal and overestimated the forest fire losses.

The new results for the Russian forests carbon sink assessment corrected according to the discussed approach and based on the State Forest Register data following the IPCC methodology are presented in this paper. This assessment for the 2015 Net Ecosystem Production (NEP) of the Russian forests is 630 ± 110 million tons C/year, including approximately 140 million tons/year accumulated in dead biomass.

It must be emphasized that the carbon sequestration capacity assessment of Russian forests presented here is the result of research and has no official status yet.

1. Introduction

Forests cover 67% of the territory of the Russian Federation and are important for stabilizing the climate in the country, as well as globally. The Forest Resource Assessment FAO UN (Global Forest Resource Assessment 2015, 2015a, 2015b, http://www.fao.org/forest-resources-assessment/en) shows that the area of Russian forests has reached 20% of the global forest area. The FRA reports that Russian forest areas without shrubs and human settlement forests (city forests) totals 814.9 million ha. A substantial part, 88%, of Russian forests grow in the boreal zone. The major forest-forming species are larch *(Larix sibirica),* pine *(Pinus sylvestris)*, spruce *(Picea abies)*, Siberian pine *(Pinus sibirica)*, birch *(Betula pendula)*, aspen *(Populus tremula),* oak *(Quercus robur)*, beech *(Fagus sylvatica),* etc. (Forest State Report, 2016). Operating with these large numbers requires exceptional accuracy. Small inaccuracies in assessing such vast areas might cause significant errors in forest policies.

Almost all Russian forest lands are included in the Forest Fund – a unique Russian term sometimes translated as "Forest Estate"

* Correspondence to: All-Russian Research Institute of Silviculture and Mechanization of Forestry (FBU ARRISMF), 15 Institutskaya street, Pushkino, Moscow region 141200, Russia.
E-mail address: nat-malysheva@yandex.ru (N. Malysheva).

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(Malysheva, 2005) – and defined as lands under federal jurisdiction. The boundaries of these lands are drawn in accordance with the Forest Code and Land legislation. Forest Fund lands comprise a majority of forests (96.9%) with the exception of forests on lands used for industry, roads, etc.; national reserves and national parks; and forest lands within human settlements (city forests). Currently, the lands of the Forest Fund are under the authority of the Federal Forestry Agency, a part of the Ministry of Natural Resources of the Russian Federation.

Forest Fund lands consist of forest lands: lands covered with forest vegetation and lands not covered with forest vegetation that are meant for forest restoration (clear-cuts, burns, etc.) at 75.4% and non-forest lands: the land serving for forest management (roads, rides, etc.) at 24.6%. The Paris Agreement allows countries to independently specify national contributions to climate change mitigation and response; declares support for conservation, sustainable forest management, and increases in carbon stocks; and reaffirms the importance of promoting non-carbon benefits (Article 5 of the Paris Agreement, 2015, http://unfccc.int/paris_agreement/items/9485.php). The Paris Agreement also highlights the importance of forests as net sinks of carbon within terrestrial ecosystems. In the context of the Paris Agreement, an objective and complete count of the carbon stock and the carbon sinks in Russian forests is of great importance. The agreement provides a reason for revising practices and improving assessments of carbon stocks and the carbon balance in Russian forests. In this article, we analyse the methods currently in use for the accounting of Russian forest sequestration capacity and their validity.

2. Materials and methods

To improve the carbon sink and carbon balance assessments of national forests, assessment methods and data categorization should be revised. We suggest three approaches: first, to revise the methods of calculating sequestration capacity; second, to revise the sub-categories of forest lands for counting; and third, to eliminate the double counting of losses from fires, timber harvesting and wood removal.

2.1. Revising methodology

The only data source for the carbon sequestration capacity and carbon balance assessment of national and regional forests is from the State Forest Register. According to the Forest Law (Article 91, Forest Code of the Russian Federation, 2006), the State Forest Register is a documented source for information on forests, their use, forest protection management and forest reproduction.

All the materials we used for our calculations were taken from the data of the State Forest Register in Russia, which are available for national reporting under international climate agreements. The State Forest Register annually updates all quality and quantity characteristics of forest management and inventory. This information reflects the changes in the areas affected by fires, cuttings, diseases and other disturbances. The State Forest Register data are presented by units of forest management (lesnichestvo) and regions. These data are collected not from sampling plots but from forest stands during forest taxation, and the procedure is implemented at different times. The evaluation of the growing stock through an inventory of forest stands can contain errors of up to 20% of the value, which is much greater than the errors that result from evaluation by sampling plots. The use of State Forest Register data requires taking into consideration the specifics of the source information, which may contain significant systematic errors (Shvidenko and Nilsson, 2002).

The Russian assessment report to the IPCC and the 7th Russian national communication under the UNFCCC (National inventory report of the Russian Federation on greenhouse gas emissions and removals, 2006) are based on State Forest Register data and the IPCC stock change method using IPCC equation 3.2.3 (Good Practice for Land Use, Land Use Change and Forestry, 2003, http://www.ipcc-nggip.iges.or.jp) for the annual assessment of carbon stock in living biomass. This type of equation requires that the inventory data be collected from permanent sample plots at two points in time.

The annual change in growing stock assessed with the State Forest Register at two points in time can in no way be interpreted as an increment for the reporting year. Taking into consideration the characteristics of statistical data, the IPCC equation 3.2.5 shown below (Good Practice for Land Use, Change and Forestry, 2003) must be used for estimating changes in the carbon stocks in living biomass.

$$G_{TOTAL} = I_v \cdot D \cdot BEF_1 \cdot (1 + R),$$

Where

G_{TOTAL} – average annual biomass increment above and below ground, tons d.m. ha^{-1} yr^{-1};
I_v – average net annual increment in volume suitable for industrial processing, m^3 ha^{-1} yr^{-1};
D – basic wood density, tons d.m. m^{-3};
BEF_1 – biomass expansion factor for conversion of the net annual increment (including bark) to the aboveground tree biomass increment, dimensionless;
R – root-to-shoot ratio appropriate to increments, dimensionless.

This equation uses the parameter “average annual net increment,” which can be obtained directly from the State Forest Register and makes the calculated numbers more accurate. We believe that for the carbon sink evaluation of Russian forests to be more accurate, this parameter should be calculated by the above equation based on the average annual net increment data from the State Forest Register.

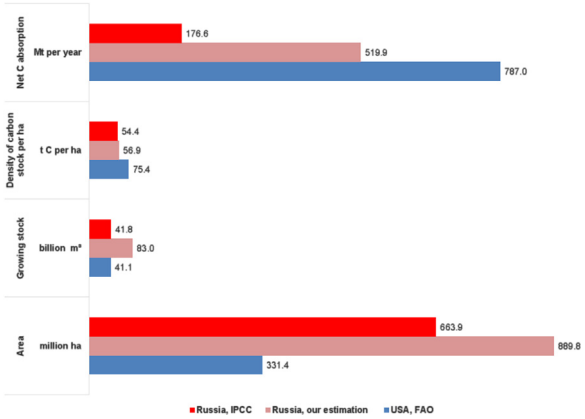

Fig. 1. A comparison of Russian and US forests' sequestration capacities (without the soil pool), where Russia, IPCC represents data from the Russian assessment report to the IPCC and the National Greenhouse Gas Inventory Report under the UNFCCC and the Kyoto Protocol (National inventory report of the Russian Federation on greenhouse gas emissions and removals, 2006); Russia, our estimation represents the FRA-2015 FAO; and USA, FAO represents US data from the FRA-2015 FAO.

The net C absorption calculated by this equation is compared with those in the Russian assessment report to the IPCC, the national inventory report under the UNFCCC and the Kyoto Protocol (National inventory report of the Russian Federation on greenhouse gas emissions and removals, 2006) and the FRA-2015 assessment of forests in the US (Global forest resources assessment 2015, 2015a, 2015b) and is shown in Fig. 1. Our assessment (pink bar graph in Fig. 1) is clearly in line with productivity (growing stock per ha).

The forest area of Russia is 2–2.5 times that of the US (Fig. 1), whereas the net C absorption of US forests is 4 times greater, other parameters being identical. We theorize that the most obvious reason for such a discrepancy is the underestimation of the area of Russian forests and the initial data used in the net carbon storage calculation and the different methods of data processing.

The situation seems to be more balanced when both factors, shown by the pink bars for net C absorption (Fig. 1), are considered.

Another methodological irregularity that must be discussed is the exclusion of over-mature[1] forests from the calculation. The absorption by over-mature forests in the national inventory report under the UNFCCC (National inventory report of the Russian Federation on greenhouse gas emissions and removals, 2006) was considered to be "zero". Nonetheless, this type of forest stores some amount of carbon, although the rate of carbon accumulation decreases in old-growth stands. The area of over-mature forest stands in Russia is more than 150 million ha. The growing stock for over-mature forests is ≈ 80 million m^3/yr. Therefore, the carbon storage of the over-mature stands should be included in the greenhouse gas inventory.

2.2. Sub-categories for counting

To improve the carbon balance assessment for the national forests, the categories of counting should be revised.

The first national greenhouse gas inventory Report on the condition and use of forests of the Russian Federation for 2015 (2016) considered only managed forests, a portion of the Forest Fund lands, and there have been no changes in this approach since then. Meanwhile, the forest lands of Russia have many other sub-categories that should be included. First, we discuss the eligible sub-categories of forest lands; second, the definition of managed forests and the consequences of applying this definition to the sub-categories of Russian forests; third, the lands not included in the Forest Fund and therefore excluded from the accounting.

The UNFCCC defines "forest" as "land area with tree crown cover (or equivalent stocking level) of more than 10–30% with trees with the potential to reach a minimum height of 2–5 m at maturity in situ. A forest may consist of either closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground or open forest. Young natural stands and all plantations that have yet to reach a crown density of 10–30 per cent or a tree height of 2–5 m are included under forest, as are areas normally forming part of the forest area that are temporarily unstocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest…"(https://unfccc.int/cop7/documents/accords_draft.pdf). This definition fits all sub-categories of forest lands in the Russian Forest Fund.

Russian Forest Fund forest lands cover a total area of 864.54 million ha. These forest lands include the following (in million ha):

- Lands covered with forests and shrub vegetation – 770.12.
- Natural forests with non-closed canopies – 60.56.
- Forest nurseries and plantations – 0.03.
- Planted forests with non-closed canopies – 1.48.
- Burnt areas – 23.59.
- Dead stands – 1.29.

[1] Over-mature forests: forest stands one age group older than the harvesting age group. (http://www.fao.org/docrep/w7707e/w7707e09.htm).

- Glades and wastelands – 2.69.
- Clearcuts – 4.78.

Of the 8 sub-categories, only one was included in the national greenhouse gas inventories, but only partially. The first sub-category, “Lands covered with forest and shrub vegetation”, was represented only by lands covered with forest. Shrubs were conspicuous by their absence. The other 7 sub-categories were all excluded. Shrubs and forests with non-closed canopies accumulate carbon in the biomass, although in different proportions, and we consider this difference in our assessment.

Following the UNFCCC guidelines and taking into consideration Russia’s Forest Fund structure, we suggest including in the accounting all forest lands: shrubs, natural forests with non-closed canopies, forest nurseries and plantations, planted forest with non-closed canopies, burnt areas, dead stands, glades and wastelands, clearcuts, etc.

Forest lands without shrub vegetation cover approximately 695.2 million ha, while the total territory responsible for carbon accumulation is much larger and is approximately 864 million ha.

The second point of revision is the definition of managed forests and the consequences of applying this definition to the sub-categories of Russian forests.

The IPCC Guidelines for National Greenhouse Gas Inventories provide methods for estimating and reporting sources and sinks of greenhouse gases only for managed forests. Countries should consistently apply the national definitions of managed forests over time.

The IPCC definition of managed forests is as follows: subject to periodic or ongoing human interventions that imply a whole range of management practices from commercial timber production to stewardship and non-commercial practices (https://unfccc.int/cop7/documents/accords_draft.pdf). The Russian Forest Fund lands are categorized as follows: protective forests, exploitable forests and so-called “inaccessible” forests (wild forests in remote areas). Only protective and exploitable forests were formerly considered managed in all national inventories; “inaccessible” forests were excluded.

“Inaccessible” forests dominate in northern-eastern Siberia and the Far East. We believe that it is a mistake to consider them as “unmanaged”. These forests are protected against fires, pest infestation and diseases in accordance with forest legislation. These areas have forest management plans at the regional and local levels. However, the areas were excluded from “managed” forests for the national GHG inventory and thus from Russian reporting under the UNFCCC and the Kyoto Protocol (National inventory report of the Russian Federation on greenhouse gas emissions and removals, 2006). This methodological ambiguity regarding “inaccessible” forests has resulted in approximately 200 million ha missing from the national assessment.

The third item to discuss is the lands not included in the Forest Fund and therefore excluded from an accounting.

There are forest land categories that are not included in the Forest Fund. These lands comprise forest lands of industrial areas, roads, human settlements, natural reserves, national parks, etc., and all together cover 26.3 million ha. We suggest that all these lands, together with the Forest Fund lands, be considered as “managed forests” in international climate agreement reports. Thus, the total adds up to 890.8 million ha. Note that Canada also plans to assess the carbon storage and emissions for all its forests, even the unmanaged forests (Boisvenue et al., 2016).

2.3. Eliminate double counting for carbon losses from fire, timber harvest and wood removal

The third approach to improving the carbon balance assessment of the national forests is eliminating the double counting of carbon losses from forest fires, timber harvest and wood removal, as the Paris Agreement (Art. 13 Ch. 4 Paris Agreement, 2015) recommends paying attention to avoiding double counting from anthropogenic emissions and carbon absorption.

Forest fires are the main factor damaging Russian forests and causing losses in accumulated carbon. Climate change has negative impacts on wildfire regimes, and the frequency of fires and areas affected by large fires are increasing. Fig. 2 demonstrates the negative dynamics of fire damage to Russian forests over the past 15 years. The losses of accumulated carbon caused by forest fires, timber harvest, wood removal and other disturbances has increased from 110 million tons C/yr to 151 million tons C/yr over the past 15 years. Forest fires are responsible for approximately 50% of these losses. The impact of these fires on forest carbon sequestration and carbon balance increases year after year and therefore requires special attention.

The double counting of carbon losses from forest fires and timber removal occurs because of the peculiar annual record keeping. The State Forest Register annually collects information on the area and volume of logging and of forest damage and destruction due to different detrimental factors, including forest fires. This information is included in the data that are used for the carbon loss

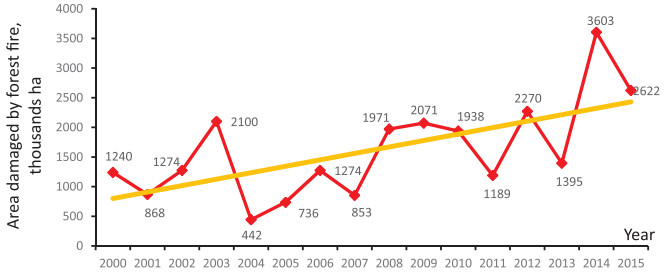

Fig. 2. Dynamics of areas damaged by forest fires during the period of 2000–2015.

calculation. Therefore, the data on areas, timber volume and growing stock already include information about annual losses. Nevertheless, the official Russian greenhouse gas inventory reports present the losses from clearcuttings in a separate column, which means these losses are counted twice. To fix the error, this amount should be added back into the total loss of carbon to prevent counting losses twice. According to the State Forest Register, the average annual volume of logging in Russia for 2005–2015 is 180 million m^3/yr. Our calculations show that the loss of carbon from clearcutting is overestimated by approximately 22 million tons C/yr.

In accordance with the requirements of the IPCC Guidelines for National Greenhouse Gas Inventories (2006), only anthropogenic emissions are estimated in national inventories. The national Russian GHG inventory considers the consequences of all fires, regardless of their origin, both natural and anthropogenic. It is rather difficult to determine the cause of a forest fire (Flannigan et al., 2009). In Russia, there is a system for monitoring forest fires. This system's database contains all the information about fires collected locally and by remote sensing and is updated daily. That is, the origin, whether natural or anthropogenic, of every forest fire is registered. Even though fires of natural origin, according to statistics, represent less than 10% of cases, they cover a very significant area. By including all types of fires in the reports, we increase the numbers for anthropogenic emissions. According to our estimation, in the Russian report for the UNFCCC and the Kyoto Protocol (National inventory report of the Russian Federation on greenhouse gas emissions and removals, 2006), the total fire losses are overestimated by ~ 20 million tons C/yr. Thus, the overestimated losses are presented for Siberia and the Far East, namely, the Krasnoyarsk Region (66.4 million tons C/yr), the Khabarovsk Region (32.9 million tons C/yr) and the Sakha Republic (64.5 million tons C/yr). These regions have the largest areas of "inaccessible" forests.

As we see, the evaluation of the carbon balance for the national GHG inventory report doubled the carbon losses caused by timber harvest and wood removal and overestimated the forest fire losses. The total gain from the correction of double losses is ≈ 42 million tons C/yr.

3. Results and discussion

The FRA-2015 FAO UN shows that the annual increases in forest growing stock for the past 25 years tended to exceed the annual forest area losses (Global Forest Resource Assessment 2015, 2015a, 2015b). The world's forest areas, as of 2015, are decreasing at a rate of 0,13% per year, whereas the growing stock per hectare is increasing at 0,16% per year. These numbers should lead to an increase in the carbon stock, but the increase is not shown in FAO data and reports. The absence of the expected direct correlation between the increase in forest growing stock and the carbon stock and the possible reasons for this absence should be discussed.

Statistical data show that the total forest area, growing stock and indicators of Russian forests' productivity have tended to increase since 1956. In light of the above results, the annual increment in the growing stock has increased from 807.9 million m^3/yr in 1956 to 1.01 billion m^3/yr in 2015. The increases in the net annual increment per ha were 1.2 m^3/ha/yr and 1.32 m^3/ha/yr, respectively (Report on the condition and use of forests of the Russian Federation for 2015, 2016). The likely reason is the impact of climate change and the increase in nitrogen deposition with atmospheric precipitation.

Carbon sequestration and the rate of carbon accumulation by the forests are directly connected to the productivity, species composition and age of stands and particularly to the rates of natural and anthropogenic disturbances.

Article 5 of the Kyoto Protocol of the UNFCCC allows the revision or correction of methodology at any point in time during commitment. Additionally, international legal instruments declare the importance of and encourage research and efforts aimed at using the "best information", meaning exhaustive, and improving data quality (Kyoto Protocol, Article 10a).

The practical application of this provision implies the improvement of methods of evaluation for the accumulation of carbon in Russia's forests and the carbon balance and the consideration of all the factors that contribute to the refinement of national reports on sinks and storage of greenhouse gasses.

The three factors that significantly affect carbon sink estimation are the methodology of calculating sequestration capacity, the sub-categories of the forest lands included for counting, and the double counting of losses. Applying the new methodological approach, changing the area of the accounted forests, and eliminating the double counting increase the carbon sink. Table 1 presents an estimate of the impact of national report improvements in terms of carbon sequestration. To calculate the sink effect for Table 1, we applied the equation, using the parameter "average net annual increment" as suggested in our article.

According to our preliminary calculations, the underestimation of the carbon sink in Russian forests equals ≈ 340 ± 75 million tons per year total. In addition, the carbon balance and carbon sequestration counts were carried out with uncertainties of more than 50%. These factors occur due to the ambiguity of assessing the carbon accumulation in certain pools (biomass, dead organic matter, litter) and the inaccuracies in the recording of carbon emissions caused by forest fires. All these factors require further research.

Our study led to the identification of the main areas with unaccounted carbon sequestration, and these areas can be illustrated by the maps. The maps (Figs. 3 and 4) show the areas with unaccounted carbon sequestration capacity for Russian forests. First, the distinct underestimation pertains to the so-called "inaccessible forests" in the remote regions of Siberia and the Far East (see Fig. 3).

According to our research, the total gain in carbon absorption after including into the count all the areas previously unaccounted for would be approximately 300 million tons C/year (Table 1).

The map in Fig. 4 shows the areas for which carbon losses by disturbances, harvesting and wood removal were overestimated. The forests of Siberia and the Far East (Krasnoyarsk Region, Khabarovsk Region and Sakha Republic) stand out in this respect. The evaluation of the carbon balance for the National Greenhouse Gas Inventory report under the UNFCCC and the Kyoto Protocol doubled the carbon losses caused by timber harvest and wood removal and overestimated the forest fire losses (National inventory report of the Russian Federation on greenhouse gas emissions and removals, 2006). The sink effect from the above factors and others is approximately 40–42 million tons C/year (Table 1).

Table 1
Underestimation of the carbon stock and overestimation of losses in the National Greenhouse Gas Inventory Report under the UNFCCC and the Kyoto Protocol.

Unaccounted carbon sequestration	Sink effect, million tons C/yr, total
Revising methodology for more accurate counting of carbon sequestration by mature and over-mature stands. Absorption for the over-mature forest is considered to be "zero". The area of over-mature forest stands is more than 150 million ha. The net annual increment in the growing stock is ≈ 80 million m^3/yr.	120
Sub-categories of the Forest Fund lands not included in the inventories: shrubs, natural forests with non-closed canopies, forest nurseries and plantations, planted forests with non-closed canopies, burnt areas, dead stands, glades and wastelands, and clearcuts. The net annual increment ≈ 40 million m^3/yr.	20
"Inaccessible forests" on Forest Fund lands are not included in "managed forests" and are therefore excluded from the calculation. The areas of inaccessible forests in remote regions are approximately 200 million ha. The net annual increment in the growing stock is ≈ 110 million m^3/yr.	70
Not all forests are included in the Forest Fund. The State Land Cadastre accounts for 56.7 million ha of forests on agricultural lands and 26.3 million ha of forest stands that are not included in the Forest Fund. The net annual increment in the growing stock is ≈ 190 million m^3/yr.	90
Double count for losses: a) timber harvesting (clearcuttings), b) dead forest stands. The amount of timber harvested in 2015 was 205 million m^3, with an average for the past 10 years of approximately 180 million m^3/yr. The dead wood biomass was ≈ 20 million m^3.	22
The losses of carbon due to destructive fires are recorded as anthropogenic emissions. According to the Federal Forestry data, 20–50% of forest fires in the Siberia and Far East regions occur because of natural causes.	20
TOTAL	≈ 342

Underestimation of carbon stock in Russian forests
СЕВЕРНЫЙ ЛЕДОВИТЫЙ ОКЕАН
Карское море
Море Лаптевых
Охотское море
Японское море
Бериново море
Балтийское море
Черное море
Каспийское море
Unaccounted carbon sequestration by forests. Net annual increment*, Mt/year
no discrepancy
slight underestimation, 10.0 Mt C/yr and less
substantial underestimation, from 10.1 MtC/yr to 47 Mt C/yr
* difference between assessment in National inventory report to IPCC and our evaluation

Fig. 3. Underestimation of the carbon stock in Russian forests.

For a more precise calculation of the carbon sequestration by Russian forests, a switch from using the State Forest Register data to using the State Forest Inventory data will be required. The 1st forest inventory in Russia from permanent sample plots is ongoing. We believe that using the inventory data from sampling plots is more appropriate for the carbon storage assessment. Russia is not the only country that revises its forest inventory compilation. A similar approach to national inventories of emissions and sinks of greenhouse gases has been successfully applied in many other countries.

4. Conclusions

It should be emphasized that the carbon sequestration capacity assessment for Russian forests presented here is the result of research and has no official status yet. For scientific reasons and for the recognition of the contribution of Russian forests to the global

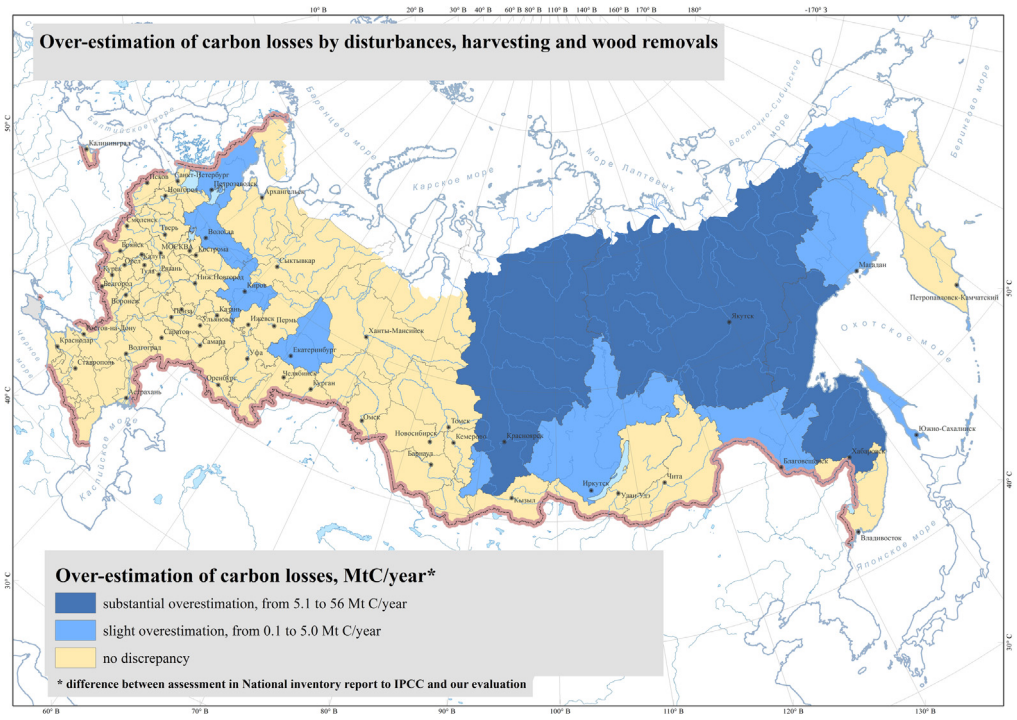
Over-estimation of carbon losses by disturbances, harvesting and wood removals
Over-estimation of carbon losses, MtC/year*
substantial overestimation, from 5.1 to 56 Mt C/year
slight overestimation, from 0.1 to 5.0 Mt C/year
no discrepancy
* difference between assessment in National inventory report to IPCC and our evaluation

Fig. 4. Overestimation of the carbon losses by disturbances, harvesting and wood removal.

carbon cycle, Russia plans to estimate the stocks and fluxes for all its forests.

The National Greenhouse Gas Inventory report on the LULUCF sector under the UNFCCC and the Kyoto Protocol should be improved, and the reporting methodology should be modified. The latest and existing methodology underestimates the carbon sink in Russian forests. The following improvements must be made:

4.1. Methodology of calculating the sequestration capacity

1. Re-calculate the average annual biomass increment with the equation that uses the parameter “average annual net increment”.
2. Take the area of over-mature forest stands into consideration.

4.2. Sub-category of the forest lands for counting

3. Include the following sub-categories of Forest Fund lands currently not included in the inventory: shrubs, natural forests with non-closed canopies, forest nurseries and plantations, planted forest with non-closed canopies, burnt areas, dead stands, glades and wastelands, clearcuts, and others.
4. Include “inaccessible” forests with “managed forests” and thus take them into account.
5. Include forests that are not under the jurisdiction of the Federal Forestry Agency (Forest Fund), such as forests on the lands used for industries and roads, human settlement forest lands, national reserves, national parks, etc.

4.3. Eliminate double counting (for losses due to fires, timber harvest and wood removal)

6. Exclude double counting for the losses caused by timber harvest.
7. Exclude the carbon losses from forest wildfires caused by natural factors, not anthropogenic ones. This point concerns the forests of Siberia and the Far East, where natural wildfires are responsible for more than 50% of the burnt areas.

As a result, the positive effect of recalculating the overestimated losses and the underestimated carbon absorption by Russian forests is approximately 340 million tons C per year.

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